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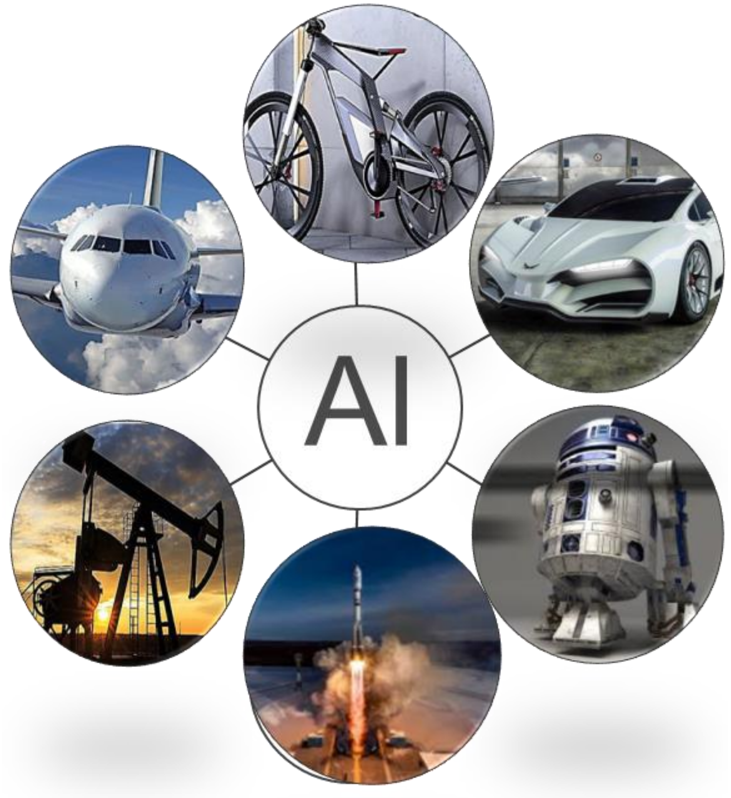

Recycling-oriented design of the Al-Zn-Mg-Ca alloys

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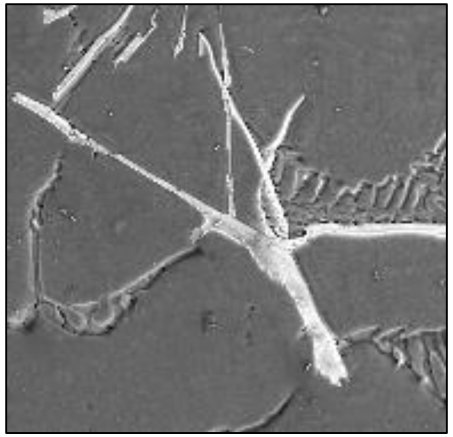
Relevance

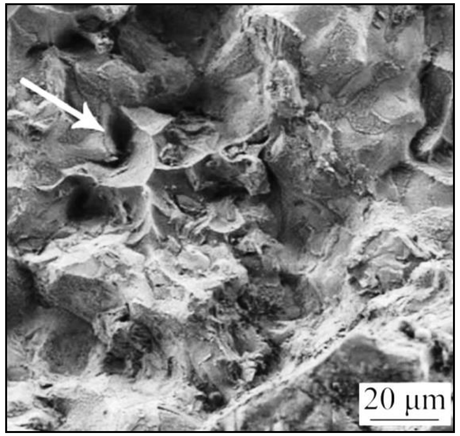
Hazardous primary Al

Hungary disaster, 2010

Krasnoyarsk, world dirtiest air 2020

Recycling saves 95% energy and reduces 90% emissions & by-products





not applicable to alloys tailored for high-strength performance (e. g. 7xxx)

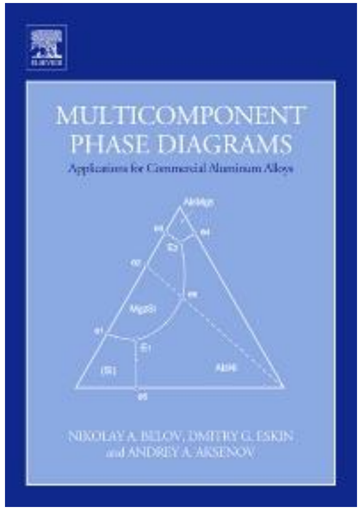
Background

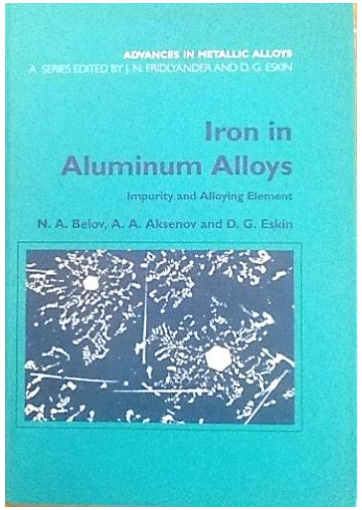
Calcium

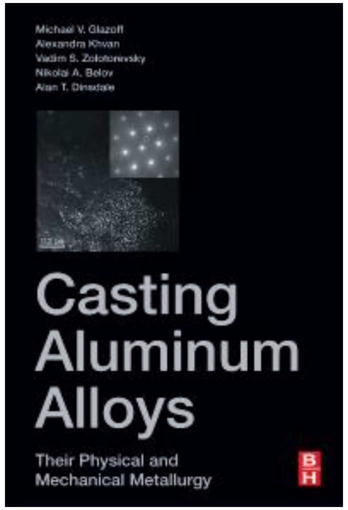
3.4 wt. % in the earth crust

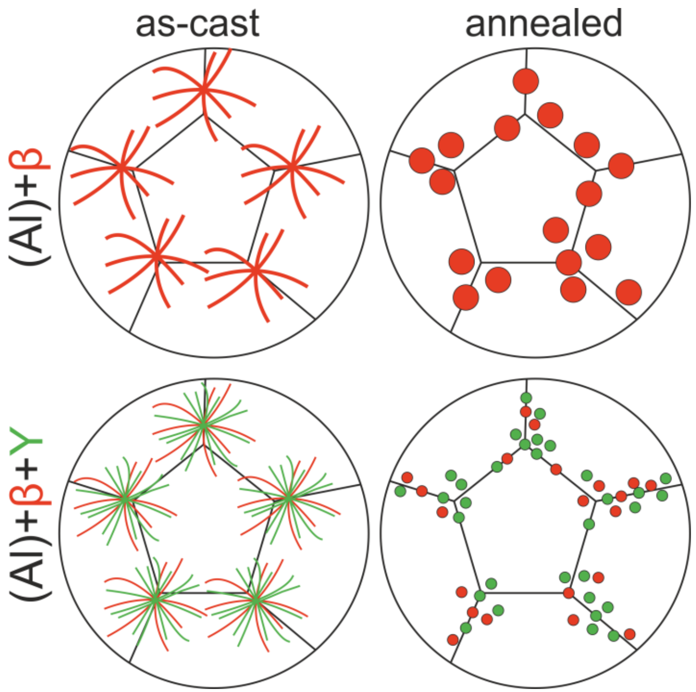
Density 1.542 г/см^3

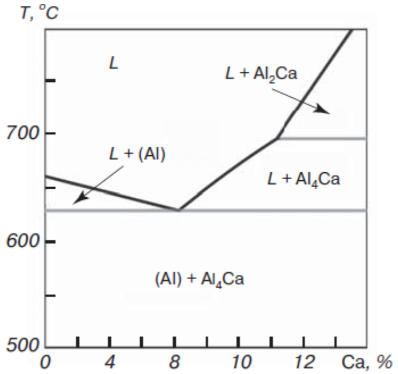
Al-7,6%Ca (31.1 vol.%Al_4Ca)











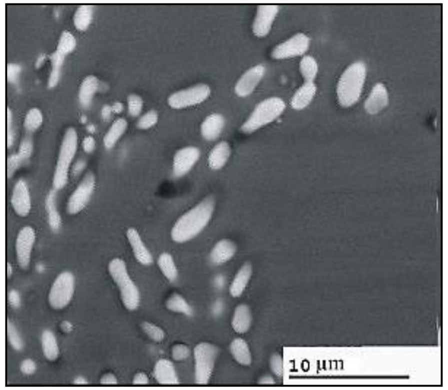
Al-Zn-Mg-Ca-(Fe)-(Si)

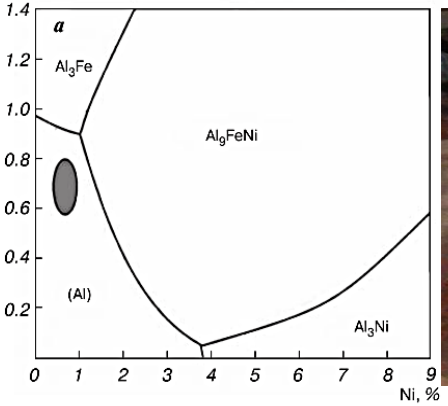
$Al_{10}CaFe_2$ Al_2CaSi_2

(Al, Zn)$_4$Ca

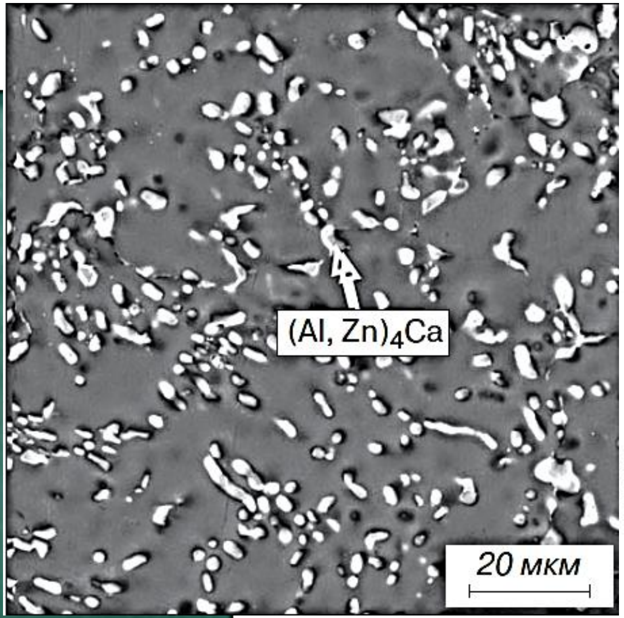
~~Al_3Fe+Mg_2Si~~

Positive experience on Al-Zn-Mg-Ni-Fe alloys (AZ6NF, Al_9FeNi as the main phase, Russian Standard 2019, Fe>0,5% UTS>520 MPa)

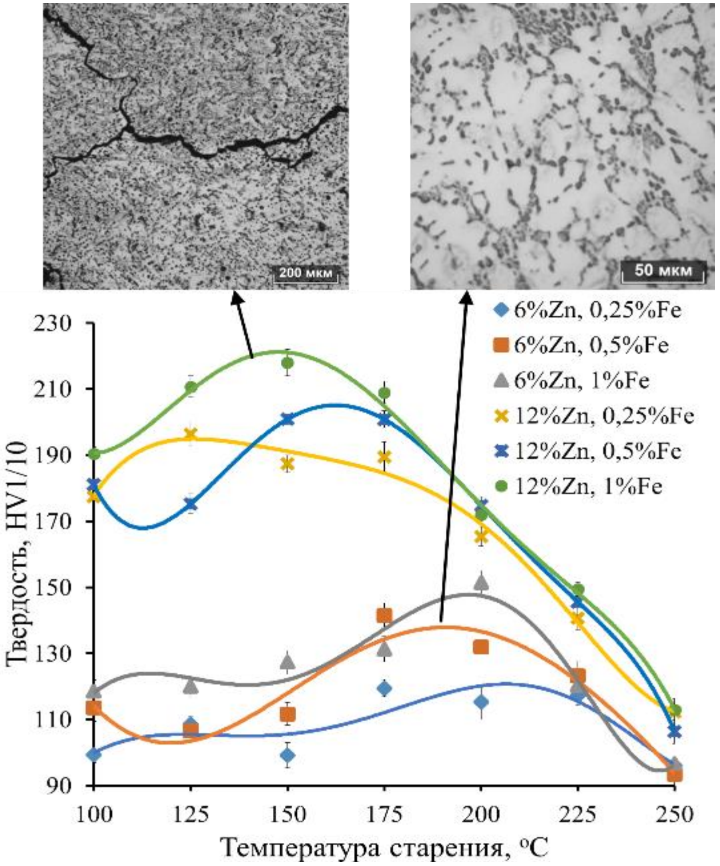




Al-Zn-Mg-Ca alloys

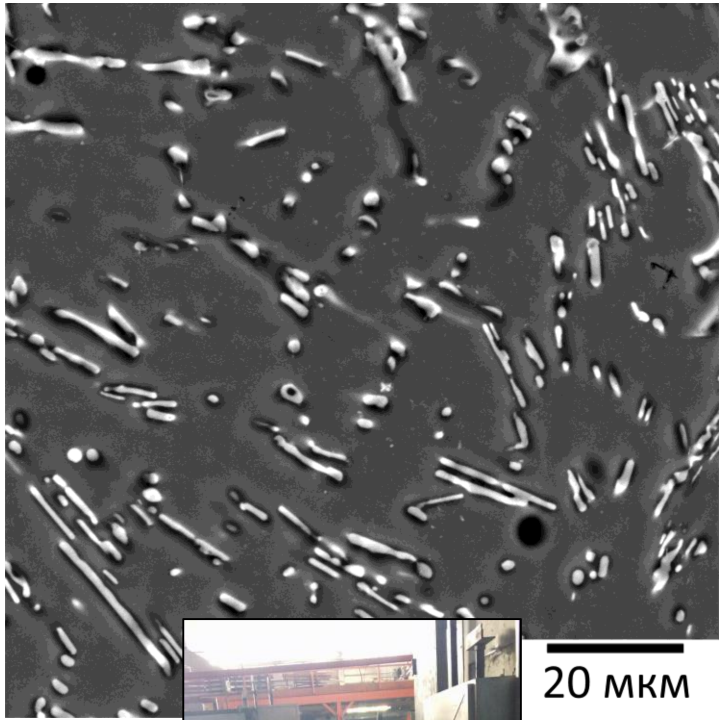


Al-9%Zn-2,5%Mg-4%Ca



Al-Zn-Mg-Fe

Al-Zn-Mg-Si



Calcium alloying process

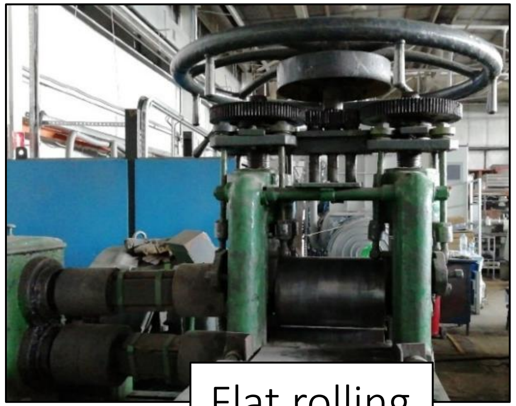
Al-Ca alloys publication activity:
- NUST MISIS>100
- Other world<10

Materials & Methods

Thermo-Calc Software

Predicting

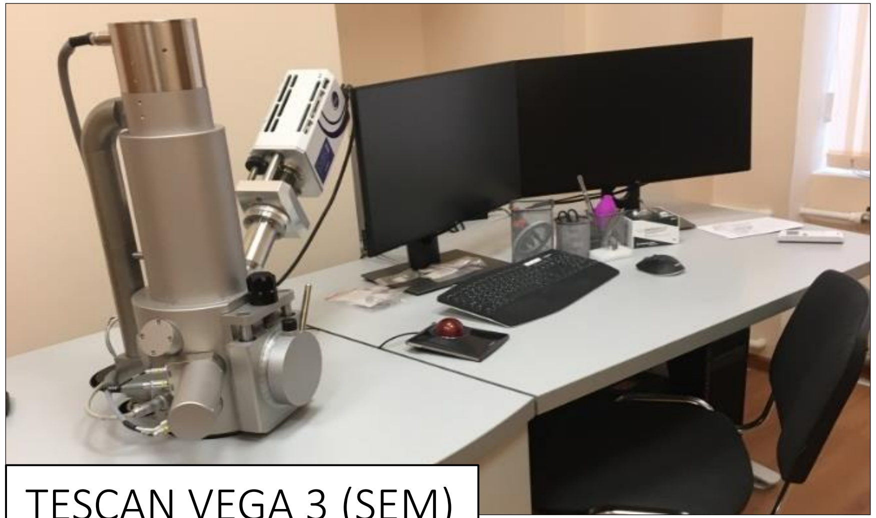
Melting and casting



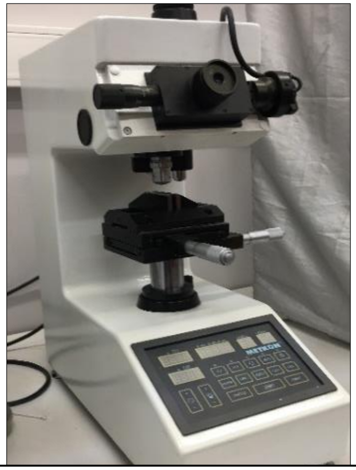
Flat rolling

Chemical compositions of the model alloys

Alloy	Nominal and actual concentrations (in brackets), wt. %					
	Zn	Mg	Ca	Fe	Si	Al
AlZnMg	8(8.1)	3 (2.8)	0	0	0	Balance
AlZnMgFeSi	8 (7.9)	3 (2.9)	0	0.5(0.51)	0.5(0.49)	Balance
AlZnMg1Ca	8 (7.7)	3 (2.6)	1(0.9)	0	0	Balance
AlZnMg2Ca	8 (7.8)	3 (3.1)	2(1.8)	0	0	Balance
AlZnMg1CaFeSi	8 (8.0)	3 (2.8)	1(0.9)	0.5(0.55)	0.5(0.51)	Balance
AlZnMg2CaFeSi	8 (7.7)	3 (2.9)	2(1.9)	0.5(0.52)	0.5(0.50)	Balance



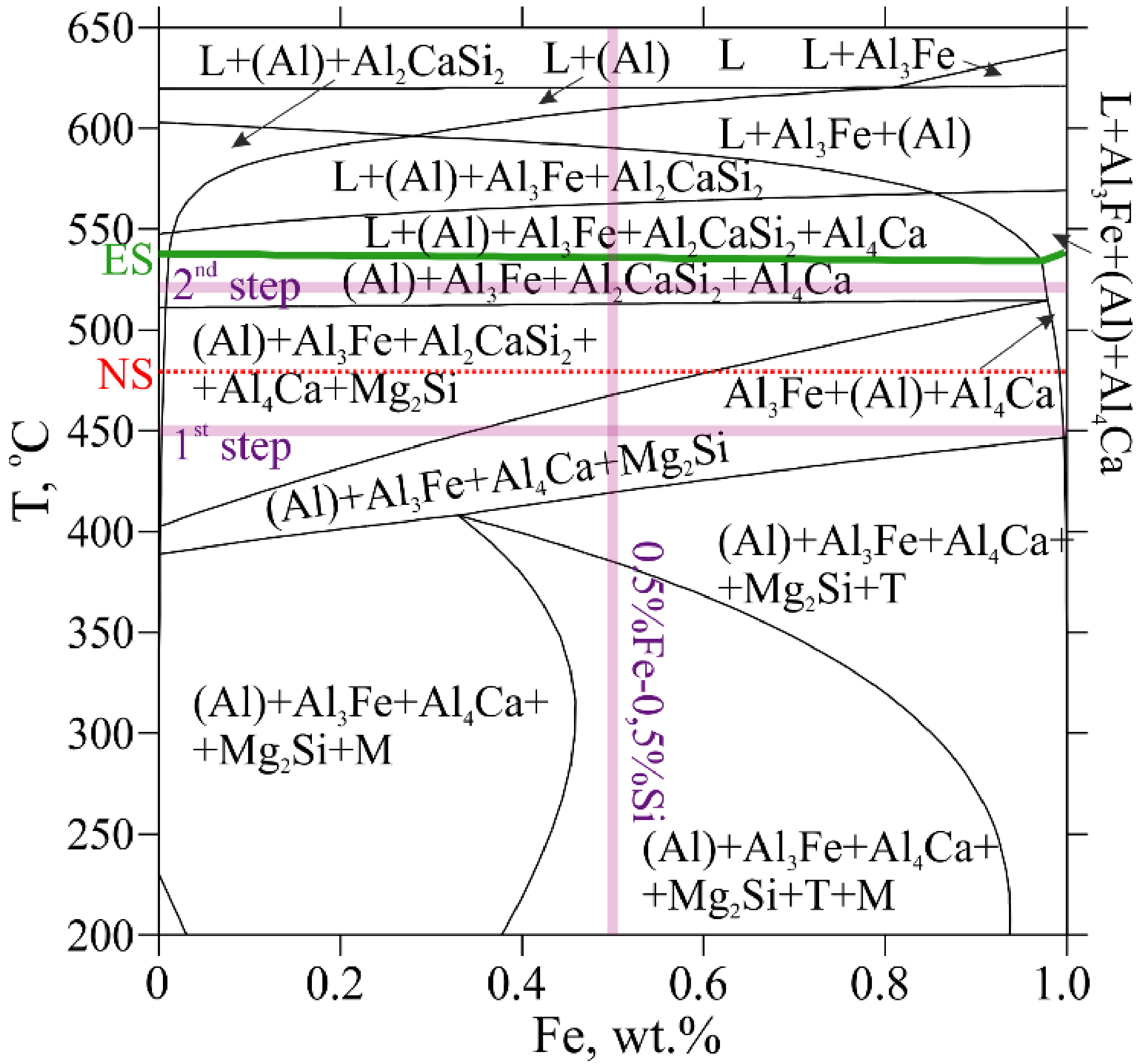
TESCAN VEGA 3 (SEM)



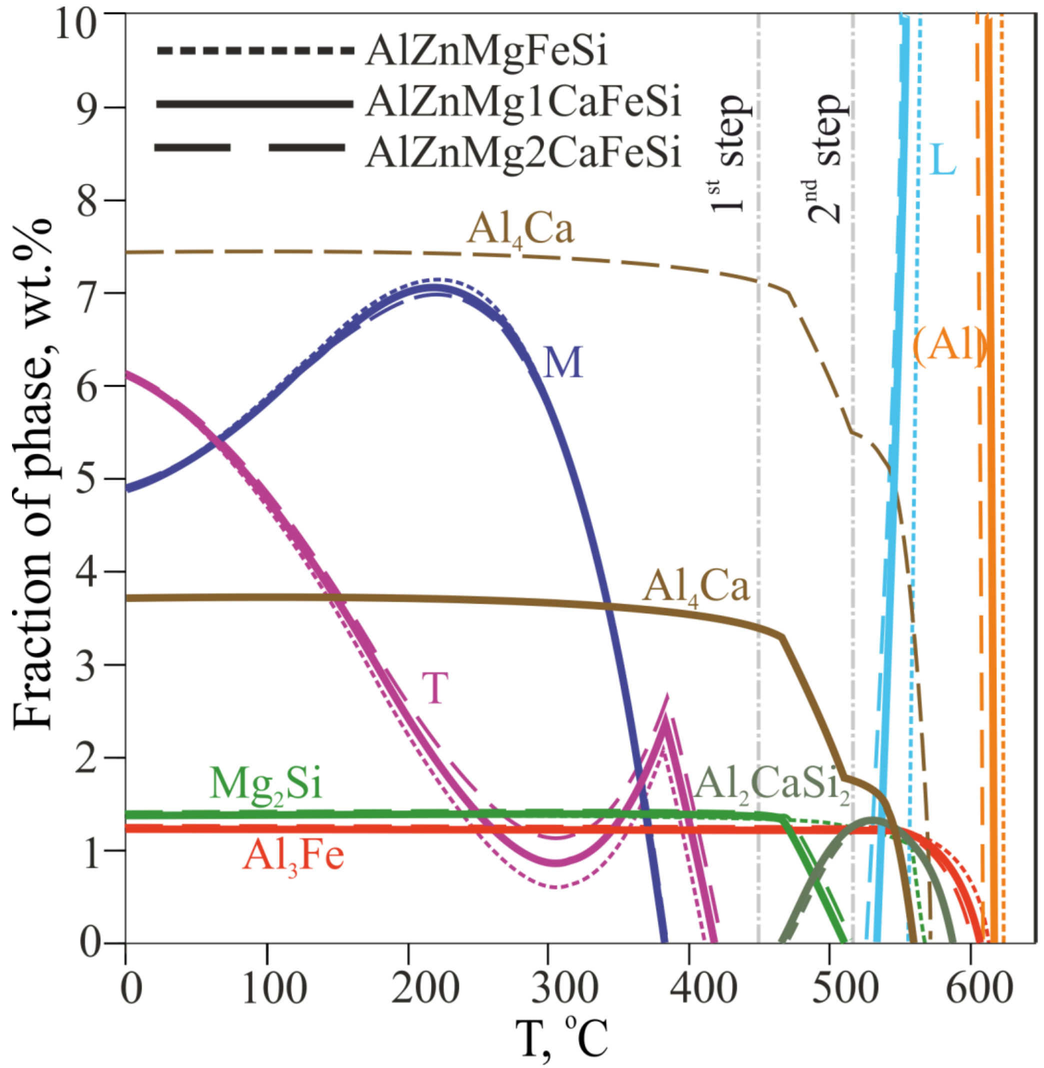
Duroline MH-6 (HV)

Thermal analysis

Solidification & Phase composition

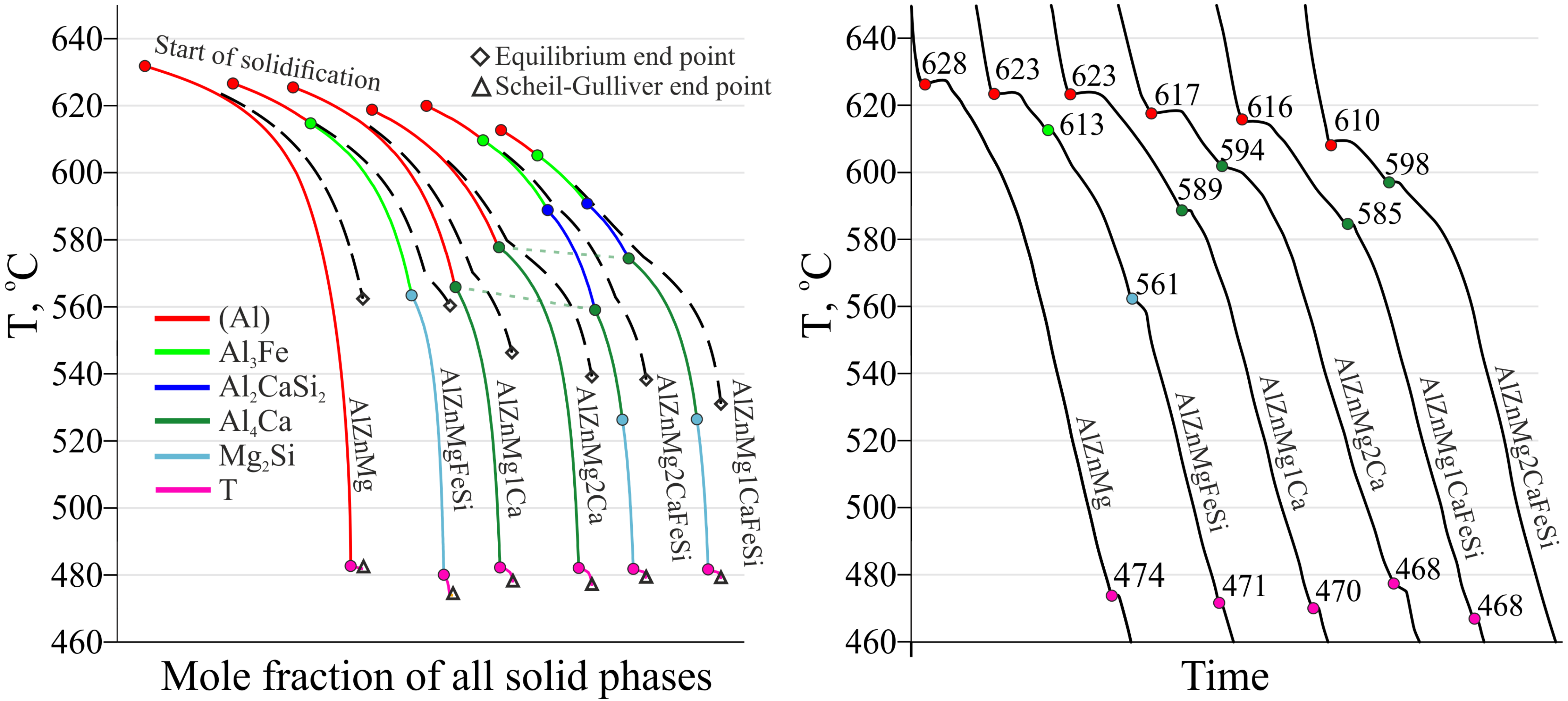


Polythermal section of the Al-Zn-Mg-Ca-Fe-Si system at 8%Zn, 3%Mg, 1%Ca and 1%(Fe+Si).



Evolution of the fraction of phases upon the temperature in AlZnMgFeSi, AlZnMg1CaFeSi, AlZnMg2CaFeSi alloys

Solidification & Phase composition

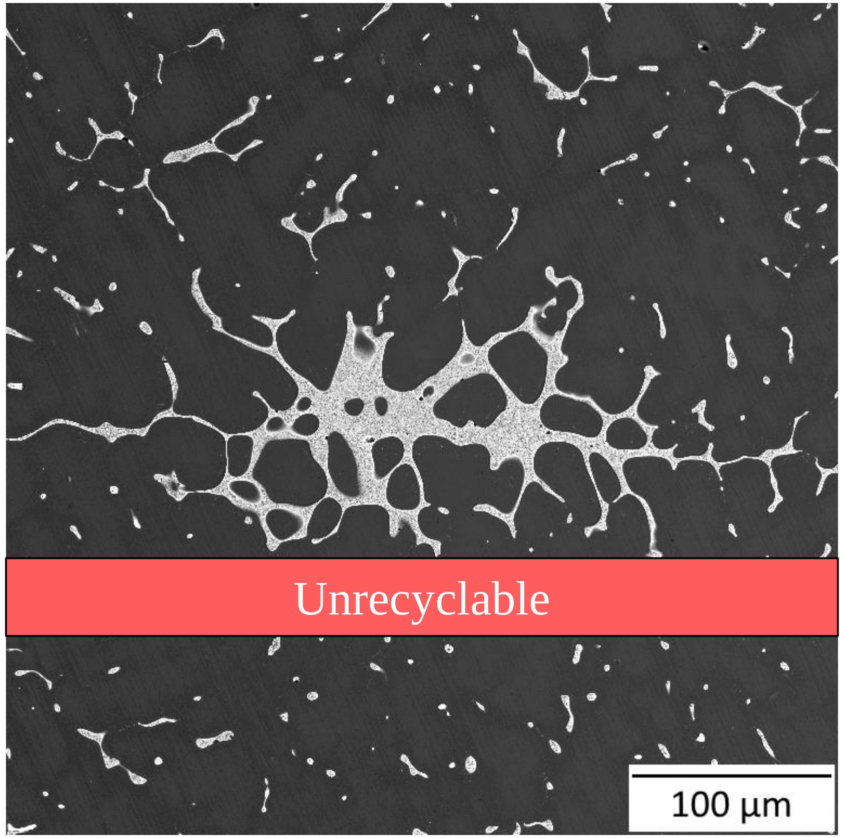


Scheil-Gulliver curves

Cooling curves

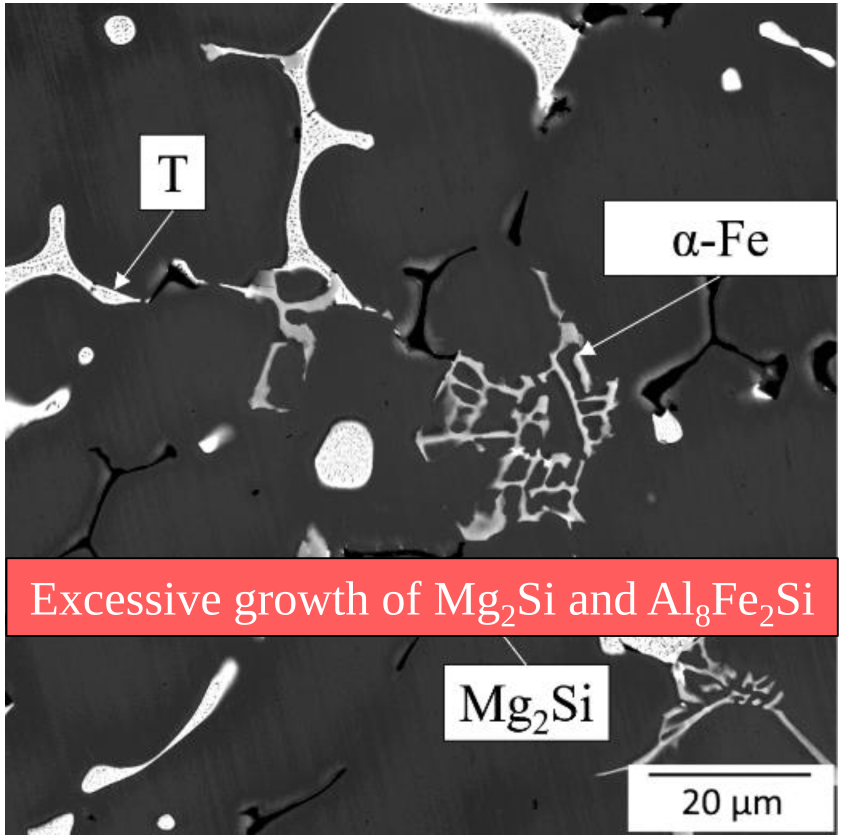
As-cast structure

(Al)+T



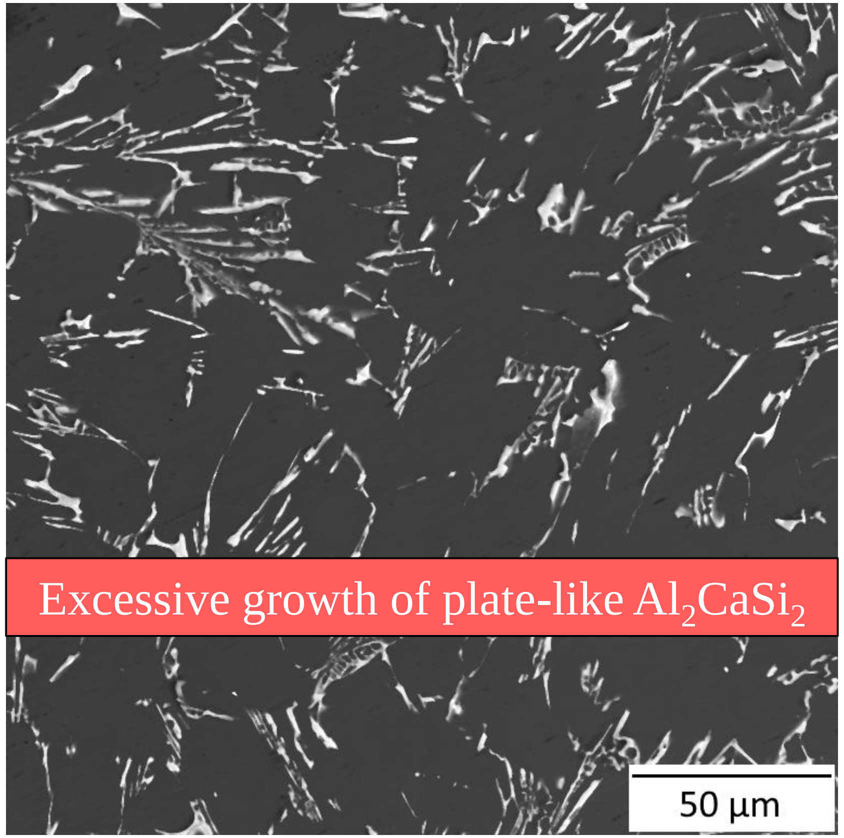
AlZnMg

(Al)+Al_8Fe_2Si +Mg_2Si



AlZnMgFeSi

$Al_{10}CaFe_2$+Al_2CaSi_2+$(Al, Zn)_4Ca$+T

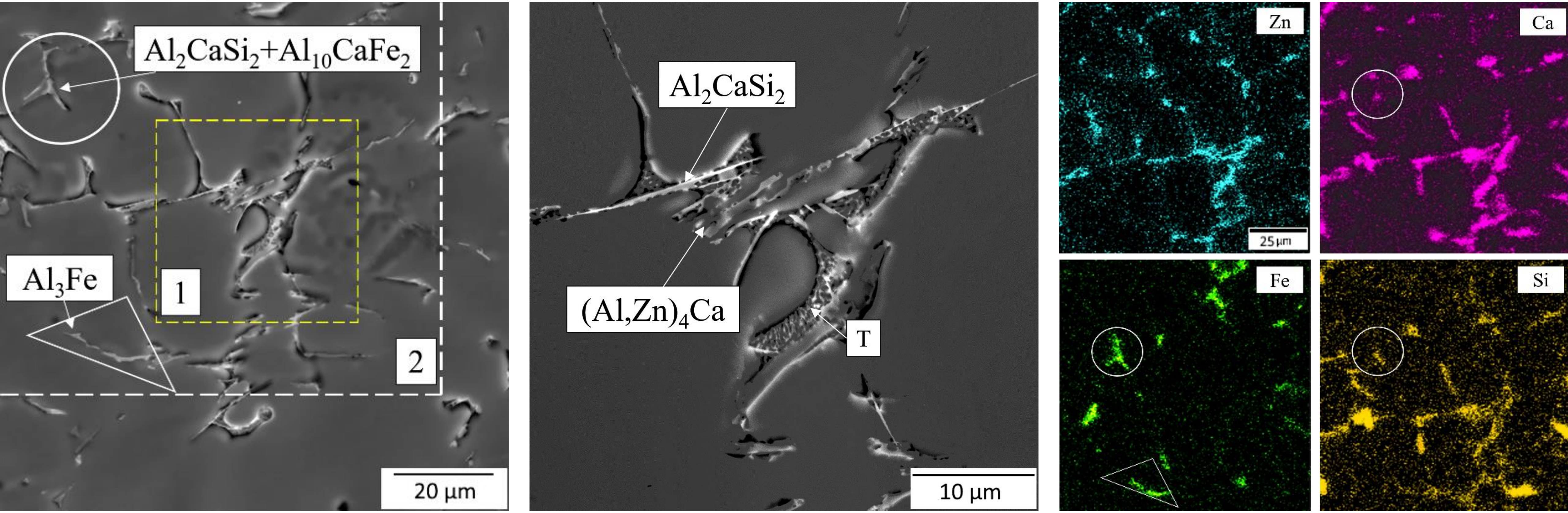


AlZnMg2CaFeSi

Calcium alloying must be rational as it promotes formation of excessive aluminides volume

Plate-like Al_2CaSi_2

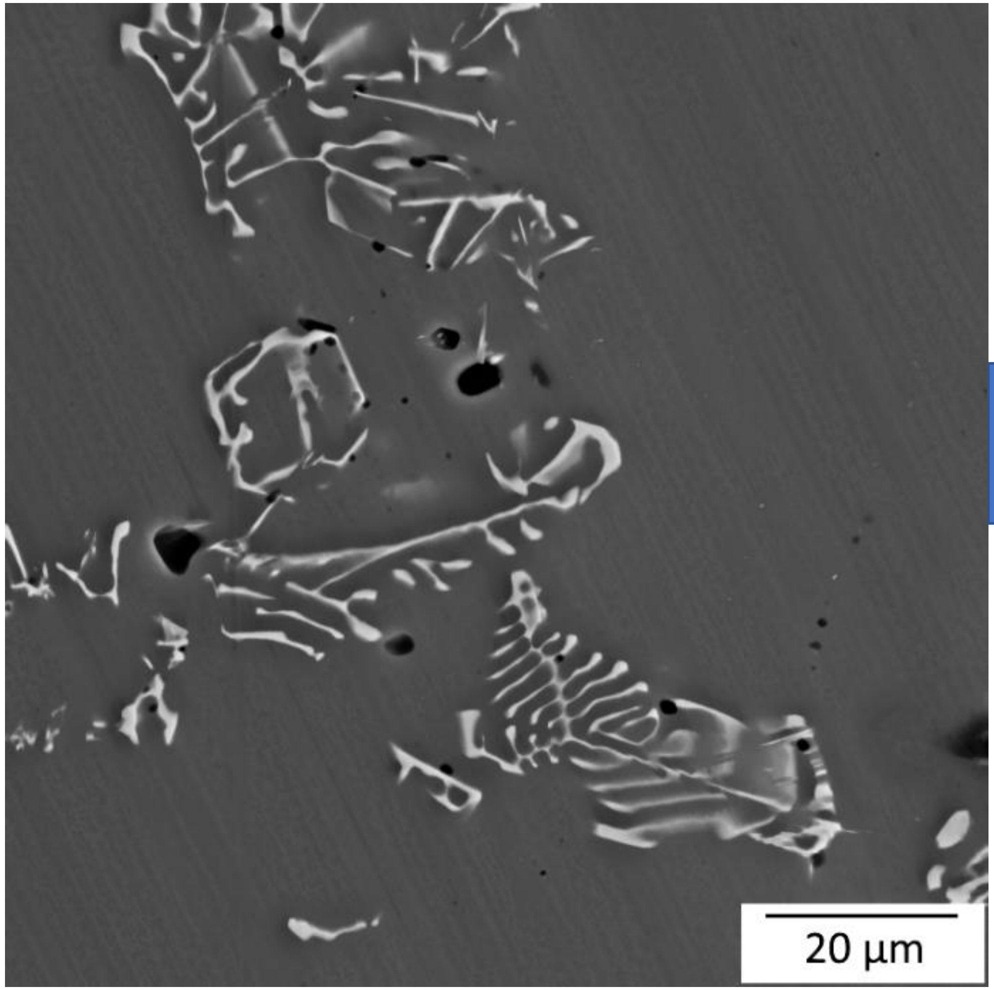
As-cast structure



AlZnMg1CaFeSi

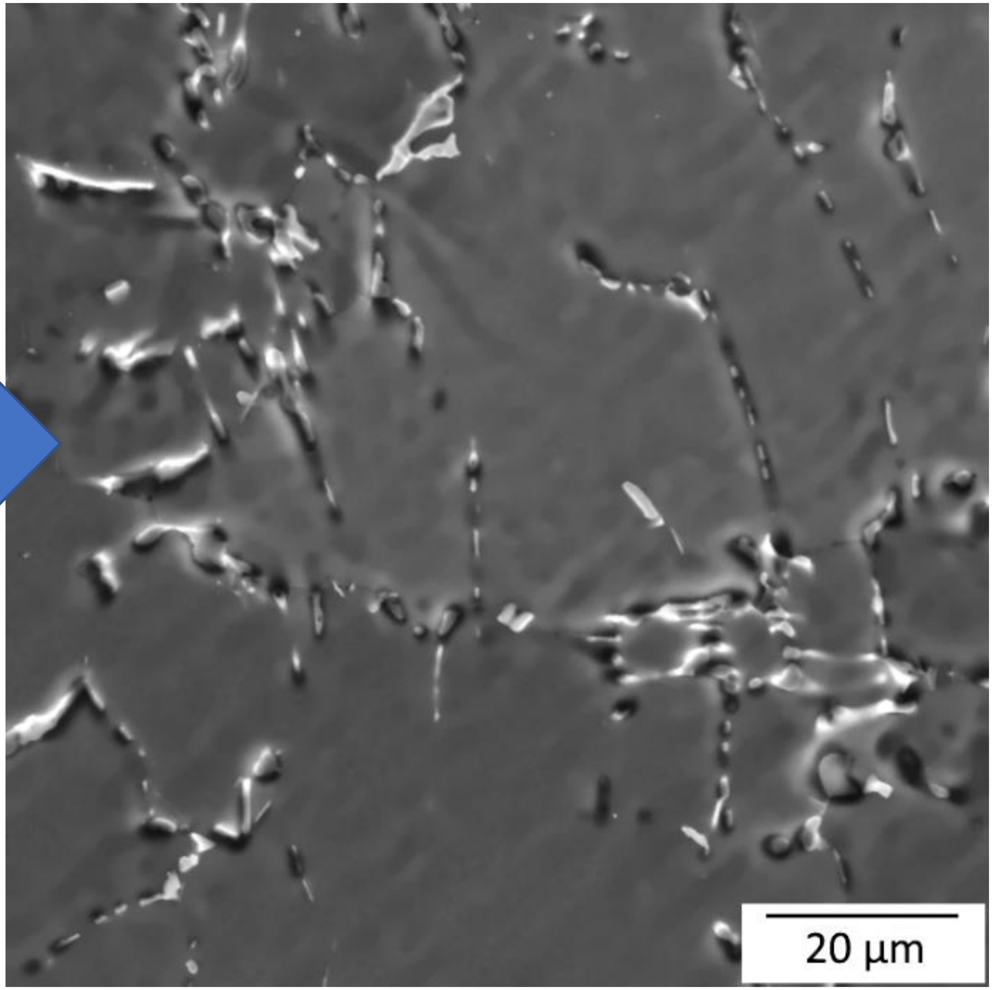
no Mg_2Si phase but Al_2CaSi_2 phase is finely needle in some places
$Al_{10}CaFe_2$ phase co-exist with Al_3Fe phase and they both are curved
Non-equilibrium T phase may be observed

Two-step annealing 450 °C,3h+520 °C,3h/water

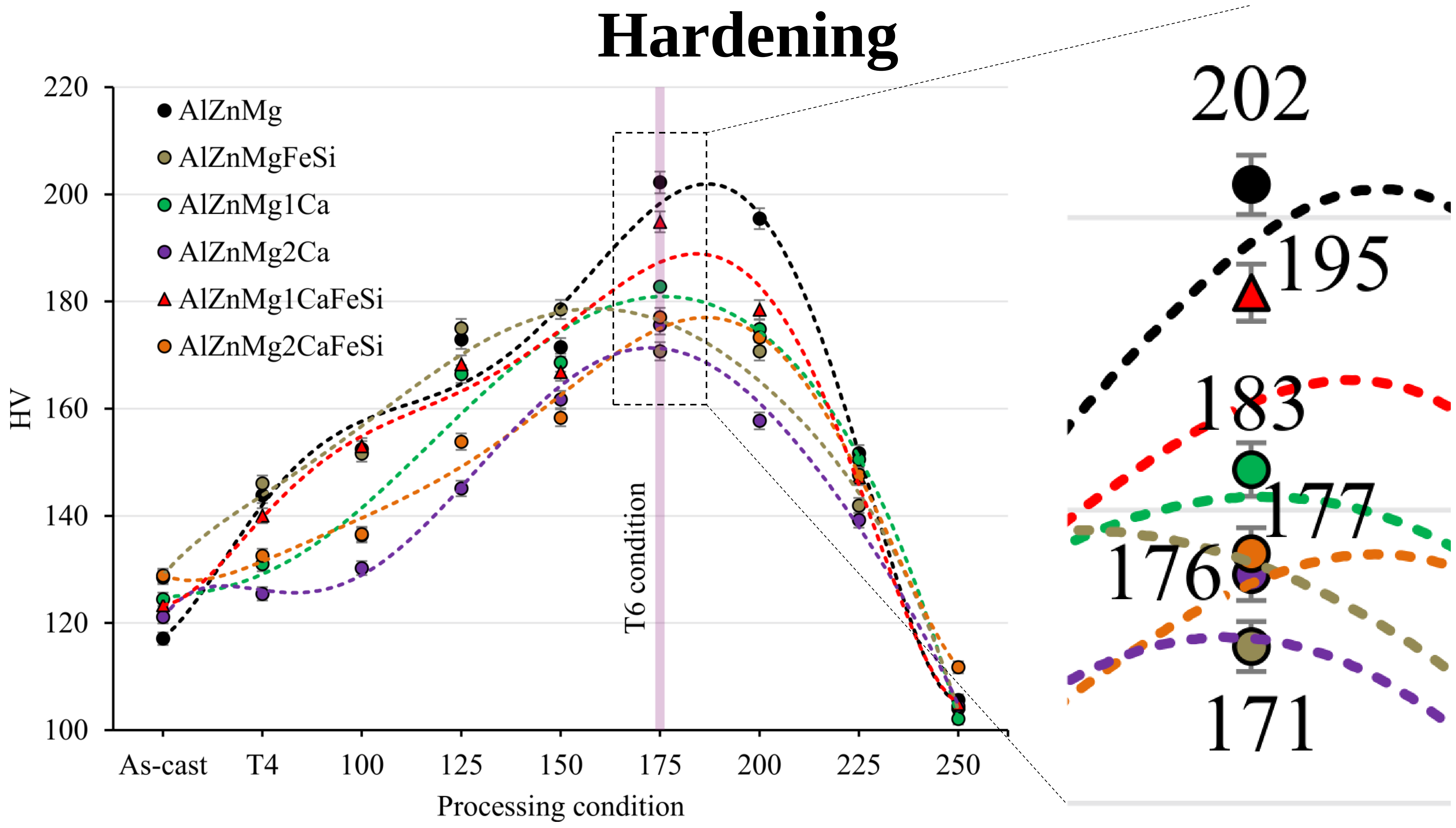


AlZnMgFeSi

+1%Ca



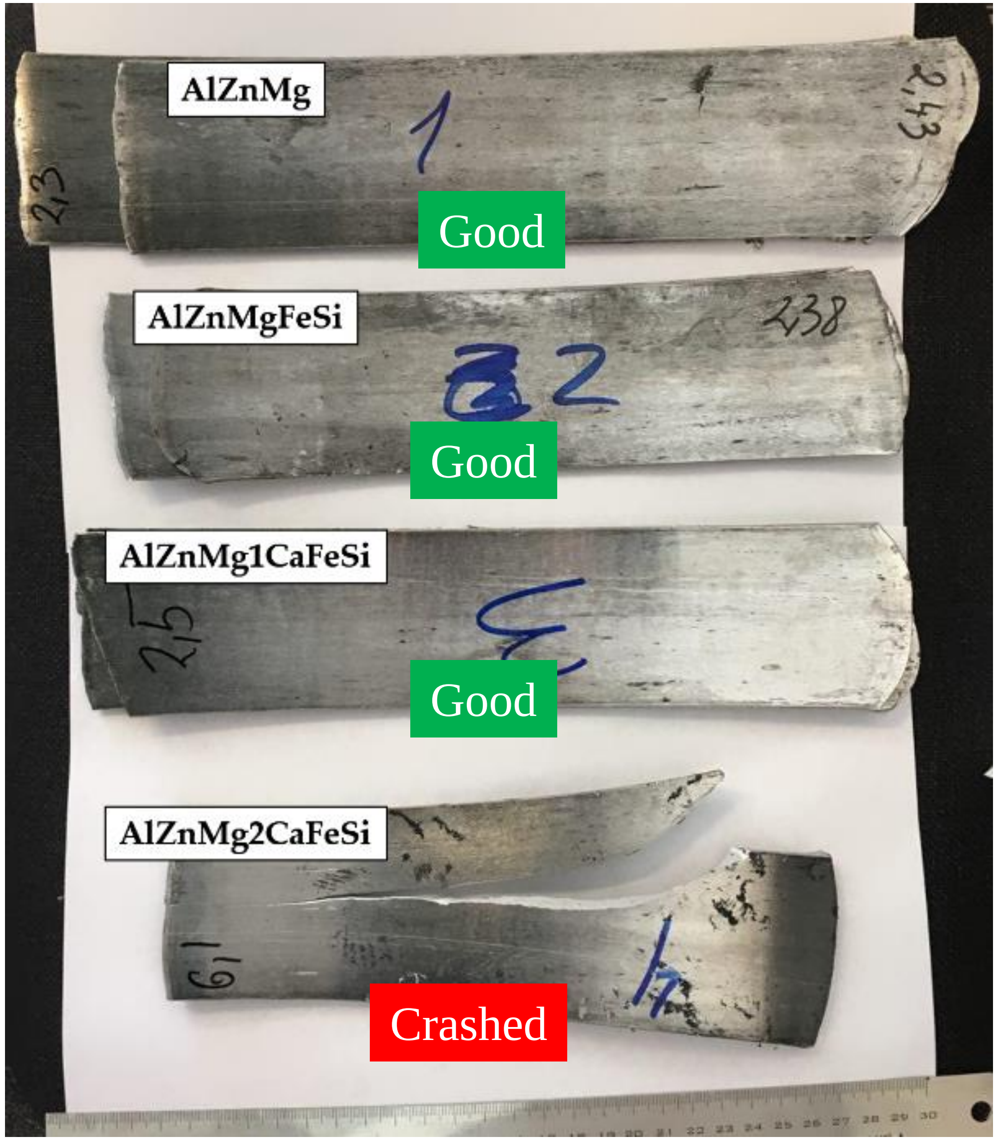
AlZnMg1CaFeSi



Hardening
AlZnMg
AlZnMgFeSi
AlZnMg1Ca
AlZnMg2Ca
AlZnMg1CaFeSi
AlZnMg2CaFeSi
HV
220
200
180
160
140
120
100
T6 condition
As-cast
T4
100
125
150
175
200
225
250
Processing condition
202
195
183
177
176
171

Deformation and recycling feasibilities

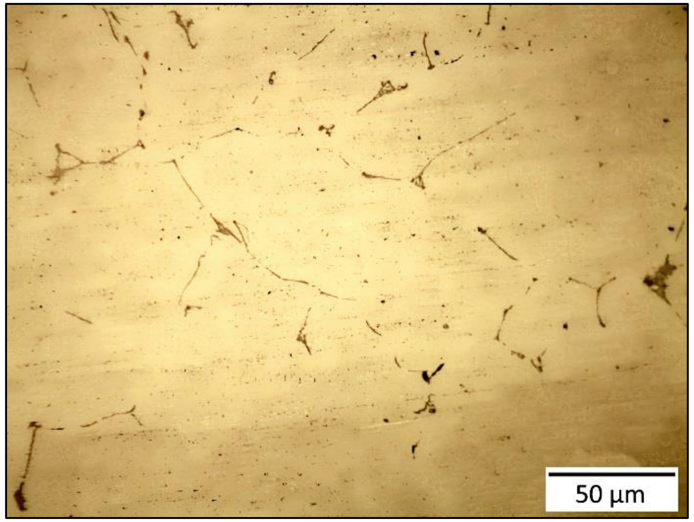
After 80% hot rolling (400 °C) reduction



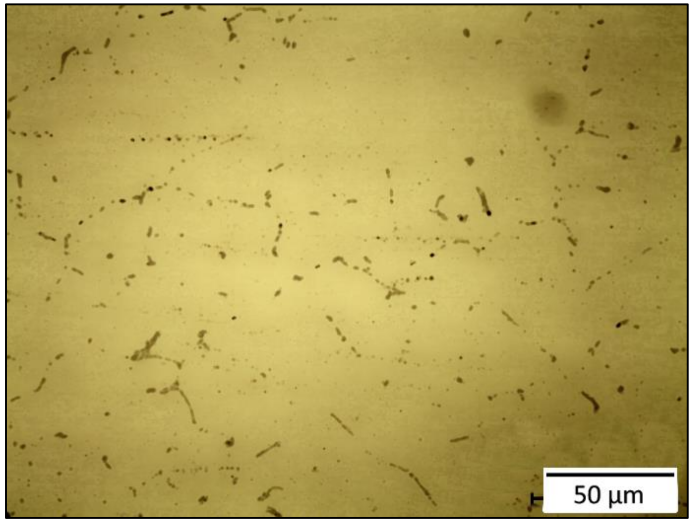
6060 and 6063 alloys are 80% recycled aluminium

JSC Aluminium Alloys Plant (Podolsk, Russia)

6063 alloy as supplied (Al-0.45Mg-0.43Si-0.37Fe-0.1Cu-0.07Mn-0.02Ti)



As-cast billet



Homogenized billet

Conclusions

1. The recycling-tolerant Al-Zn-Mg-Ca alloys may be formulated via appropriate alloying and solidification conditions provided as-cast structure included multiphase eutectic with differentiated insoluble intermetallics which must contain impurities of recycling origin, primarily, Fe and Si.

2. The phase composition and solidification path of the Al-Zn-Mg-Ca-Fe-Si alloys showed the presence of multiphase eutectic (Al)+Al_3Fe+Al_2CaSi_2+Al_4Ca under equilibrium solidus of 540 ^{o}C. However, the first annealing step at 450 ^{o}C is required for the dissolving of the non-equilibrium eutectic solidified at ~480 ^{o}C.

3. In comparison to AlZnMgFeSi and AlZnMg2CaFeSi, the AlZnMg1CaFeSi exhibited fine as-cast structure included differentiated constituents of equilibrium origin Al_3Fe, $Al_{10}CaFe_2$, Al_2CaSi_2 and $(Al.Zn)_4Ca$. After two-step annealing, they were mostly spheroidized along with non-equilibrium T phase was dissolved in (Al).

4. While the Al-Zn-Mg-Ca alloys lose their performance due to Zn dissolution in $(Al, Zn)_4Ca$ phase the joint Ca, Fe, Si alloying promotes the formation of Ca-bearing phases and an increase in solute Zn in (Al). The AlZnMg1CaFeSi in T6 possess a similar hardness value as the base AlZnMg alloy (195 HV vs 200 HV).

5. The composition related to the AlZnMg1CaFeSi alloy may serve as a sufficient basis for the design of the new high-strength recycling-tolerant wrought Al alloys since it shows good microstructure similar to that of 6xxx alloys, excellent hardening response, appropriate processability at metal forming, and may be formulated from Fe- and Si-rich aluminum scrap.

Thank you for attention!

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